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Individual Difference Variables as Predictors of Error during Multitasking

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14. ABSTRACT

Multitasking (MT) performance requires performing multiple tasks, appropriately shifting attention and prioritizing them. Successful multitaskers focus their attention on the task where attention is most needed at the moment, and they adapt to changes in task priority as they occur. It is this latter feature of multitasking that suggests a natural relationship with adaptive performance; the capability to adapt to changing task priorities is essential for effective complex task performance, and failure to do so is likely to result in performance errors. As a result of frequent or unclear priority shifts, errors in multitasking performance can be common. The primary focus of the current study is on types of performance errors committed during MT performance, namely errors of commission (i.e., addressing a task demand incorrectly) and errors of omission (i.e., allowing a task demand to lapse). Empirically, the present study examines MT performance on SynWin, a computerized multitasking work environment. Researchers investigated predictors of errors and rate of error-making within a structural model that included a complement of cognitive variables (e.g., working memory, perceptual speed) and non-cognitive variables (e.g., state anxiety, personality). Results indicated that working memory and state anxiety predicted errors of commission, and perceptual speed and state anxiety predicted errors of omission.

15. SUBJECT TERMS

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Foreword

Multitasking (MT) performance requires performing multiple tasks, appropriately shifting attention and prioritizing them. Successful multitaskers focus their attention on the task where attention is most needed at the moment, and they adapt to changes in task priority as they occur. It is this latter feature of multitasking that suggests a natural relationship with adaptive performance; the capability to adapt to changing task priorities is essential for effective complex task performance, and failure to do so is likely to result in performance errors. As a result of frequent or unclear priority shifts, errors in multitasking performance can be common. The primary focus of the current study is on types of performance errors committed during MT performance, namely *errors of commission* (i.e., addressing a task demand incorrectly) and *errors of omission* (i.e., allowing a task demand to lapse). Empirically, the present study examines MT performance on SynWin, a computerized multitasking work environment. Researchers investigated predictors of errors and rate of error-making within a structural model that included a complement of cognitive variables (e.g., working memory, perceptual speed) and non-cognitive variables (e.g., state anxiety, personality). Results indicated that working memory and state anxiety predicted errors of commission, and perceptual speed and state anxiety predicted errors of omission.

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Individual Difference Variables as Predictors of Error during Multitasking

For many individuals, multitasking has become an essential requirement of modern home and work life due to general increases in the pace of life, broadening of work roles, and expectations for individual performance and productivity (Bühner, König, Pick, & Krumm, 2006). Multitasking can be generally described as the performance of multiple tasks in a relatively short time period, with shifts in attention among the tasks (Oswald, Hambrick, & Jones, 2007). Multitasking can be challenging not only as a result of the task demands themselves but also due to the additional process of organizing and prioritizing the tasks within a time span that may either be limited or unknown to the individual or team that is performing. In fact, it may be task organization and prioritization that are the hallmarks of multitasking performance when the tasks to be performed are already well learned. For this reason, a person's capability to adapt to changing task priorities may be critical to his or her performance during multitasking, and the failure to shift one's attention accordingly may result in serious performance errors.

This paper focuses on individual differences that produce *performance errors* in a multitasking environment. Performance errors are worthy of study because they are likely to be commonplace in complex performance environments, such as those requiring multitasking. An example may best illustrate this phenomenon. Imagine that an executive assistant is completing an expense form on the computer while answering occasional and intermittent telephone calls and also fielding questions from workers as they enter the office. Any of these individual tasks might be performed on its own with ease, but in combination they may be overwhelming or distracting. This in turn may lead to performance errors: giving incomplete or incorrect information on the phone or to the workers, or making errors in filling out the expense form. Such errors—particularly if they go unnoticed and uncorrected—are likely to be detrimental to individual and organizational performance. In addition, errors during multitasking may be not only commonplace but also costly in a variety of ways. It is not very difficult to imagine circumstances under which errors could have strong negative consequences (e.g., neurosurgeon, nuclear power plant operator). Because errors are both common and potentially very important to outcomes, it is essential to better understand the types of performance errors that may occur, and to attempt to better explain their antecedents.

Imagine accidentally performing surgery on the wrong arm of a patient, or not detecting an incoming enemy warplane. These two examples are *errors of commission* (performing an incorrect action) and *errors of omission* (not performing a correct action), respectively. Even a cursory literature search shows that these two general types of errors have been examined across numerous research disciplines such as decision-making (e.g., Gilovich, Medvec, & Chen, 1995), medicine (e.g., Overhage, Tierney, Zhou, & McDonald, 1997), clinical psychology (e.g., Losier, McGrath, & Klein, 1996), human factors (Fields, Wright, & Harrison, 1995), and occupational safety (e.g., Wallace & Chen, 2006). Though the above two examples are somewhat extreme, it is apparent that both errors of commission and errors of omission have the potential to occur during multitasking, and that such errors are likely to be related to one's ability (or inability) to shift attention as task priorities change (see Figure 1).

A model of error making proposed by Endsley (1988), though it is intended to be applicable to all performance situations, is particularly relevant to multitasking. The Situation Awareness (SA) error taxonomy proposes that performance errors are due to failure to perceive the elements of the current situation accurately, the significance of the elements as a whole, and the potential future implications of the situation. During multitasking, it is essential that a person be aware not only of the components of a single task, but also of all tasks he or she is currently performing—with tasks dynamically occurring and interacting in real time. Failure to have this awareness and to perceive shifts in these tasks is likely the antecedent of critical errors.

The fluid nature of the task environment likely affects the capability of individuals to perceive and act upon the task environment accurately. Holding this multitasking environment constant, we propose that both cognitive and non-cognitive characteristics of the individual likely have an impact as well. More specifically, we think that four major individual differences predict multitasking performance:

Working memory should predict how well information about various task priorities and status is encoded, stored, and retrieved while the tasks themselves are being performed. Research on overall multitasking performance has, in fact, found working memory to be a significant predictor of overall multitasking performance (Salthouse, Hambrick, Lukas, & Dell, 1996). Thus we hypothesize:

> *H1: Working memory will be negatively correlated with errors of commission.* The inability to recall whether a task was completed or how to correctly perform a task should result in a greater number of active mistakes, or errors of commission. For example, a secretary who is entering data into a computer and is interrupted by a phone call might return to the data entering task in the wrong place, duplicating something he or she has already entered or believing the task is finished when in fact it is not. By contrast, working memory will not be related to errors of omission. When a shift in task priority occurs, the failure to act should not depend upon one's capacity for memory, but instead one's capacity for recognizing the shift and attending to the newly important task.

Perceptual speed is both a cognitive and psychomotor factor that should predict how quickly people can switch among tasks, and how quickly they can recognize that a different task has become important. Thus,

> *H2: Perceptual speed should be positively correlated with errors of omission.* Those high in perceptual speed should be better able to switch among tasks quickly as priorities shift, and thus should commit fewer "misses"—where action should be taken and is not. Perceptual speed should not; however, be related to errors of commission. Having the ability to perceive changes in task priority quickly enough to act does not guarantee that the act taken will be correct—simply that an action will be taken.

In addition, it has long been known that noncognitive factors are also important in the prediction of performance. The same is likely true for the prediction of error. For instance, multitasking has the potential to create high levels of *anxiety* in the performer (e.g., Cohen, 1980; Delbridge, 2000). It is hypothesized that:

> *H3: Anxiety will be positively correlated with errors of commission.* In a situation where an individual becomes overstimulated or highly anxious, it is not hard to imagine that he or she might begin to take action quickly and haphazardly, resulting in greater active errors. In contrast, anxiety will not be related to errors of omission, because although high levels of anxiety might impair performance at a task that is being attempted, if a task is not attempted at all, anxiety should not play a role.

In addition, *conscientiousness* has been shown to be a valid predictor of work performance across settings (e.g., Barrick & Mount, 1991), thought to be due to its relationship with individuals' diligence and achievement orientation toward a task. In multitasking, it is hypothesized that those high in conscientiousness will pay more attention to the tasks and will more diligently monitor for changes in task priority. Thus:

> *H4: Conscientiousness will be negatively correlated with errors of omission.* Conscientiousness will not be related to errors of commission, however, for much the same reason as perceptual speed. The ability to notice changes in task priority and to act does not determine whether the action taken is correct or incorrect.

Figure 2 provides a model that integrates the four hypotheses just described.

In order to test these hypotheses, we will report results from a computerized multitasking simulation that records mouse-click data on correct performance and on errors in performance for each participant over time (see Figure 3).

Method

Participants

Participants were 125 undergraduate students recruited from introductory psychology courses at Michigan State University, who participated voluntarily in exchange for course credit. Sixty-eight percent were female, 40 percent were freshmen, 27 percent were sophomores, 27 percent were juniors, and 6 percent were seniors or above. The mean age was 19.1 years, but 68 percent of students were between 18–19 years of age. The majority of the sample (75%) was non-Hispanic Caucasian, with the remainder being 10 percent Asian, 7 percent African-American, 4 percent Hispanic, with 4 percent classified as other/unidentified. Some participants were identified as outliers due to their extreme (greater than 4 SDs from the mean) scores on multitasking performance, and some failed to complete a vast majority of the measures. Thus, these cases were excluded from the analyses and 102 participants made up the final sample used for this analysis.

Materials and Procedure

Participants were tested in a laboratory setting in small proctored groups of 4–10 individuals tested across two sessions, each session taking approximately one and one-half hours. Measures relevant to the present paper are as follows:

Session 1. In Session 1, after completing a demographic questionnaire, participants completed two working memory tasks. In *operation span*, participants were presented with equation-word pairs such as: "IS (12 / 3) + 3 = 6? DOG." For each pair like this, the task was to indicate whether the equation was correct or incorrect, and also to remember the word. After 2–6 pairs were presented, a recall prompt appeared, and the task was to report the words in the order in which they appeared. In *symmetry span*, each trial consisted of a matrix, with some cells filled, followed by an arrow. The task was to judge whether the pattern in the matrix was symmetrical along the vertical axis, and then to remember the direction of each arrow. After 2–6 pairs, a recall prompt appeared, and the task was to report the direction of the first arrow, the second arrow, and so forth.

After the working memory tasks, participants then completed two perceptual speed tasks. In *letter comparison*, stimuli were pairs of letters separated by a line such as "XJK ___ XRK." Participants were to write S on the line if the pairs were the same or D if they were different. In *pattern comparison*, the task was the same, except that the stimuli were geometric patterns. In both tasks, the goal was to make as many comparisons as possible in 30 seconds. Following these perceptual speed tasks were two abstract reasoning tests. In *matrix reasoning*, each item consisted of a 3 × 3 matrix in which each cell contained a pattern except the one in the lower right-hand corner; the task was to choose the missing pattern from among eight alternatives a pattern that made logical sense. Eight minutes were allowed for 14 items. In *letter sets*, each item consisted of five sets of letters; the task was to infer the rule that made these letter sets similar and to identify the letter set that did not fit this rule. Eight minutes were allowed for 14 items.

Finally, following this set of cognitive tasks, participants completed 50 items from the International Personality Item Pool (IPIP) to measure five dimensions of personality: Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness. Each item was a statement such as "I am the life of the party" or "I feel comfortable around people." The participants' task was to rate each item on how well it described them, using a 5-point Likert-style scale.

Session 2. In Session 2, participants performed nine 5-minute blocks of the synthetic work task, called SynWin. Block 1 was a "practice" block, Blocks 2–5 were "performance" blocks, and blocks 6–9 were "emergency" blocks. For the present study, data from the performance blocks (2–5) will be used (in the "emergency" blocks the pace was doubled and the payoff parameters changed). Figure 3 illustrates the parameters for Blocks 2–5. Immediately following block 5, participants completed a measure of state anxiety. The measure consisted of 20 words describing emotions (e.g., frustrated, calm). Participants indicated on a 5-point Likert-style scale the degree to which each of the emotions described how they felt during the SynWin task.

Results

Results are displayed in the path model in Figure 1. The four solid paths from exogenous to endogenous variables reflect the four hypotheses proposed between individual differences and errors of commission and omission (correlations between the 4 exogenous variables were also modeled; they are equal to the correlations shown in Table 1). Three of the four paths were statistically significant and in the direction of the proposed hypotheses (all tests are t tests on the path coefficients, b, with $df = 16$): Working memory was negatively related to errors of commission ($b = -.20$, $p = .02$); perceptual speed was negatively related to errors of omission ($b = -.17$, $p = .01$); and anxiety was positively related to errors of commission ($b = .25$, $p = .002$). Our post hoc modification to the model indicated that anxiety was also significantly related to errors of omission ($b = .25$, $p = .002$; this path was constrained to be equal to the anxiety → errors of commission path). Conscientiousness was not significantly related to errors of omission, though the trend was in the hypothesized direction ($b = .13$, $p = .15$). The amount of variance accounted for in errors of commission and errors of omission were similar ($R^2 = .11$ and .12, respectively). Note that the variance accounted for in the error criteria is conservative in the sense that we did not model unsystematic errors of measurement that could attenuate modeled relationships. That said, the reliability estimates for non-cognitive measures were high (.85 and .91), and reliability coefficients for these cognitive measures are typically high as well (often around .9).

Regarding the additional path added to the model from anxiety to errors of omission, the decision to include this path was based on a sensible post hoc explanation. Anxiety was a state measure administered just after the SynWin performance blocks were administered. As such, this state measure is much more proximal to performance—and errors in performance—than conscientiousness is. Therefore, there is reason to believe that anxiety has direct influences on both errors of commission and errors of omission; it can cause one to react quickly to gain points, even at the expense of errors of commission, and it can cause confusion that leads one to forget to attend to one of the component tasks, resulting in errors of omission. However, the influence of state anxiety on error certainly requires further thinking and empirical replication in an independent data set.

Discussion

Understanding the process of error-making in multitasking has the potential to be a valuable undertaking due to the frequency with which errors are committed and the sometimes dramatic consequences of these errors, both for the individual and for the organization. In this paper, we used a computerized multitasking simulation to examine two types of errors: errors of commission and errors of omission. As was hypothesized, working memory was found to be related to errors of commission, while perceptual speed was found to be related to errors of omission. Additionally, state anxiety during the multitasking scenario was related to both types of error. Finally, conscientiousness was not related to either type of error. The finding that different types of cognitive ability are differentially predictive of the types of errors an individual commits suggests that future research in the area should examine these relationships to understand multitasking performance and error more precisely. In addition, the finding that state anxiety predicted both types of error highlights the importance of searching for predictors that are associated with a person's emotional experience during multitasking.

It is important to note that the study takes a relatively narrow focus on performance *outcomes*, but errors can surface anywhere in the stream of intentions, planning, and actions that leads to the final behavioral outcome. Furthermore, the outcomes toward which performers strive may shift over time or be ill-defined. In this study, the standardized and controlled nature of the SynWin task makes the research tractable and allows the link between behaviors and outcomes to be nearly isomorphic with one another (i.e., the points and penalties received correspond with the participants' behaviors or lack thereof). In real-world settings, such relationships may not be as straightforward; for instance, a Navy ship may steer off course despite all Sailors performing correctly in that situation (e.g., due to an irreparable equipment failure), or said ship may remain on course despite some Sailors performing ineffectively (e.g., because the onboard equipment autocorrects for human error). A closer examination of the components of error-making should be a valuable future addition to this area of research.

In addition, it is important to note the limitations of the current study and to suggest ways in which future research might address these issues. Participants in this study were college students, and although this sample probably generalizes well to such populations as incoming Sailors or new entrants into the workforce, further research must be done to examine the relationships found here in older and more diverse samples. This is particularly true as a result of the negative association between perceptual speed and age (Salthouse, Hambrick, Lukas, & Dell, 1996). In addition, the model tested in this paper was fairly simplistic as a result of sample size limitations. Future research should examine more complete models, including a variety of other situational and dispositional variables. In total, this paper provides a preliminary investigation of a phenomenon that is likely to be important in the coming years, and provides a starting point for future research to further examine types and components of errors and their potential antecedents and consequences.

Table 1
Descriptive Statistics, Reliabilities and Correlations

Scale	Mean	SD	1	2	3	4	5	6
Cognitive Variables								
1. Working Memory	.02	.85	1.00					
2. Perceptual Speed	.02	.76	**.32**	1.00				
Noncognitive Variables								
3. Anxiety	51.94	13.98	-.13	**-.21**	(.91)			
4. Conscientiousness	34.36	6.81	-.15	-.04	-.18	(.85)		
MT Errors								
5. Errors of Commission	29.48	20.60	**-.22**	-.07	**.22**	.06	1.00	
6. Errors of Omission	16.38	21.39	-.10	**-.24**	**.31**	.09	.16	1.00

Note. Correlations in bold are significant at $p < .05$. Variables 1 and 2 are in *z*-score units, but the mean is not exactly 0 due to removal of outliers.

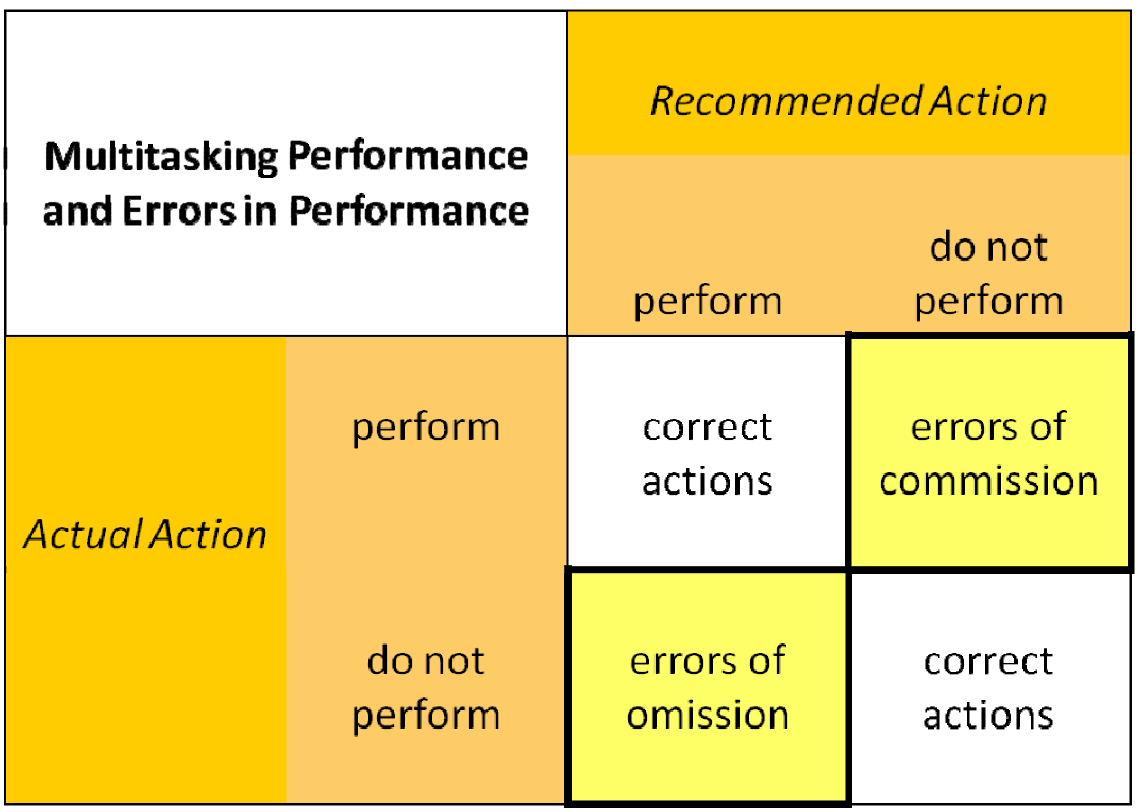

Figure 1. Errors in multitasking performance.

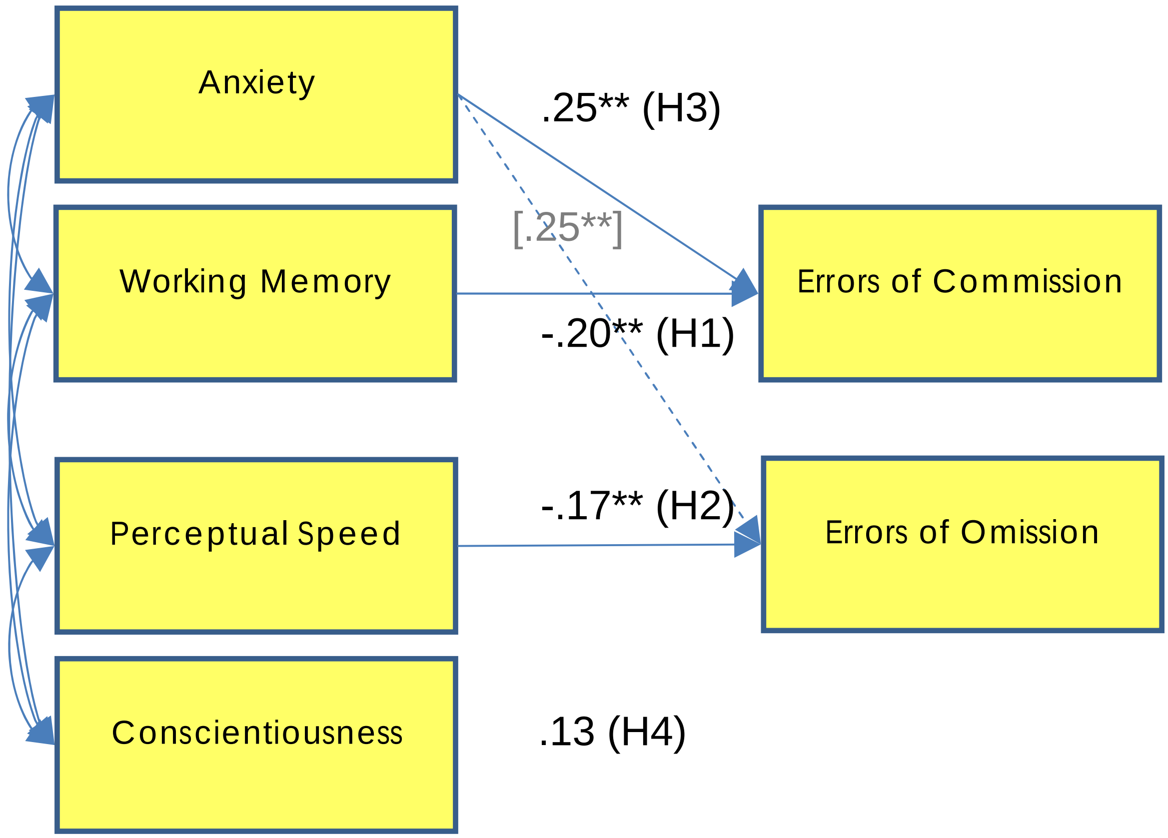

Figure 2. Structural equation model of hypothesized relationships.

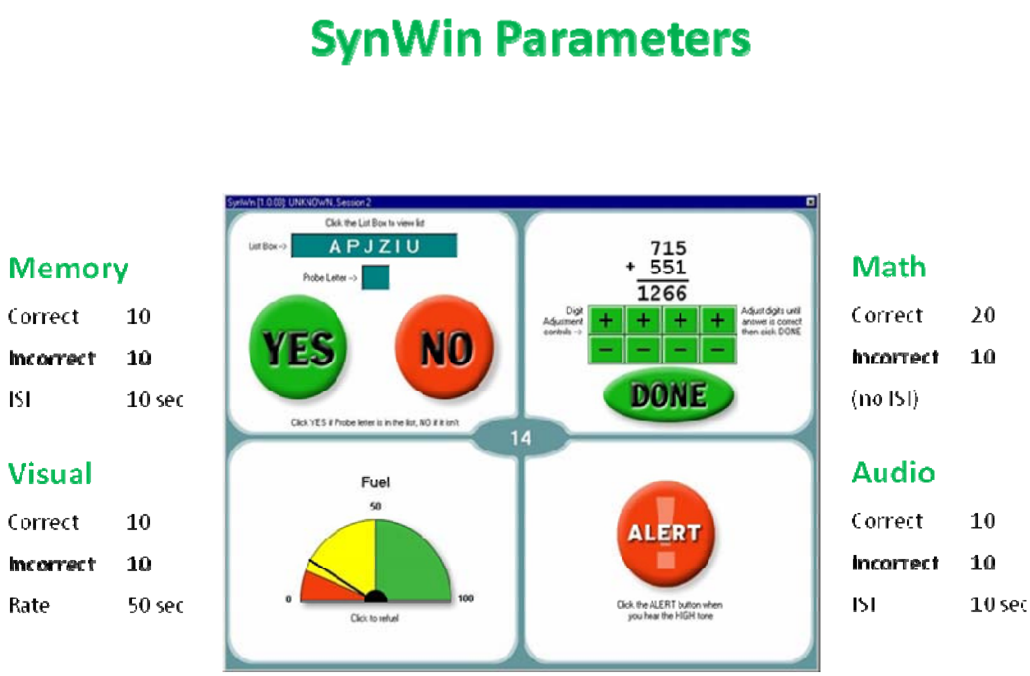

Figure 3. SynWin multitasking performance parameters.

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